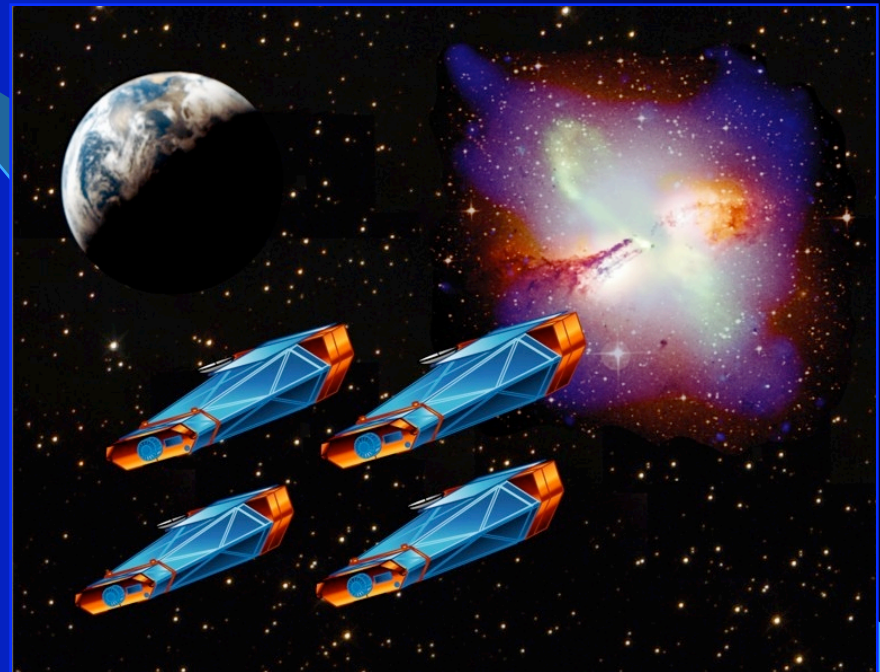


AGN and Black Hole Physics with Constellation-X

Chris Reynolds

Department of Astronomy &
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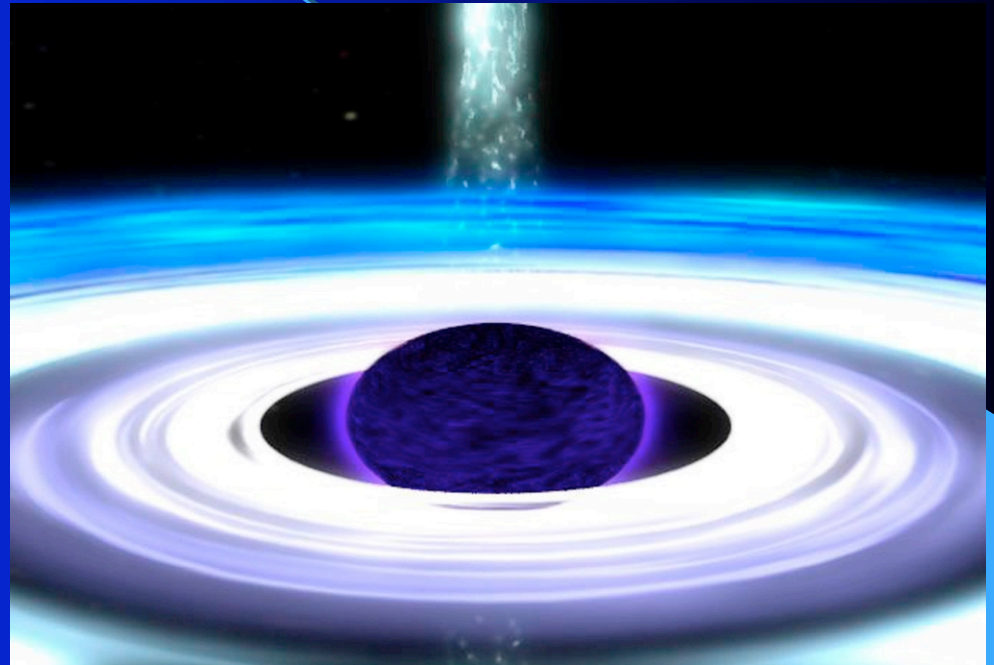
AGN Science Objectives

- λ **Core “Beyond Einstein” objectives...**
- λ Strong Gravity
 - Is GR correct in the strong-field domain?
- λ Relativistic matter and fields
 - Physics of accreting plasma close to black holes
 - Testing the electromagnetic part of GR
 - Formation and physics of relativistic jets
- λ Other AGN-stuff
 - Structure of the central engine as function of AGN type
 - AGN populations out to high redshift

**Core science is best addressed
through detailed studies of
relativistically broadened emission
lines from inner accretion disk
(iron $K\alpha$ line, in particular)**

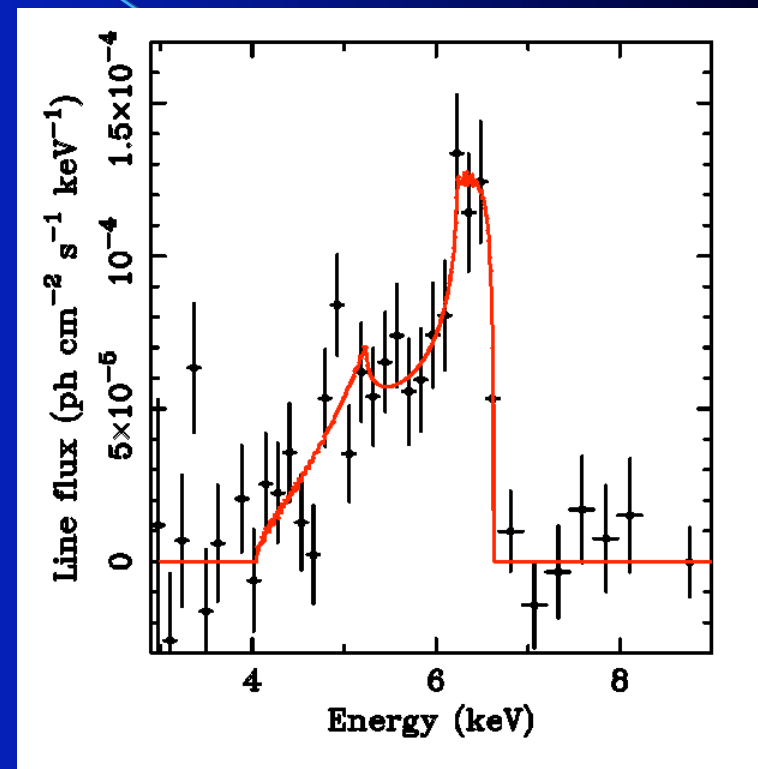
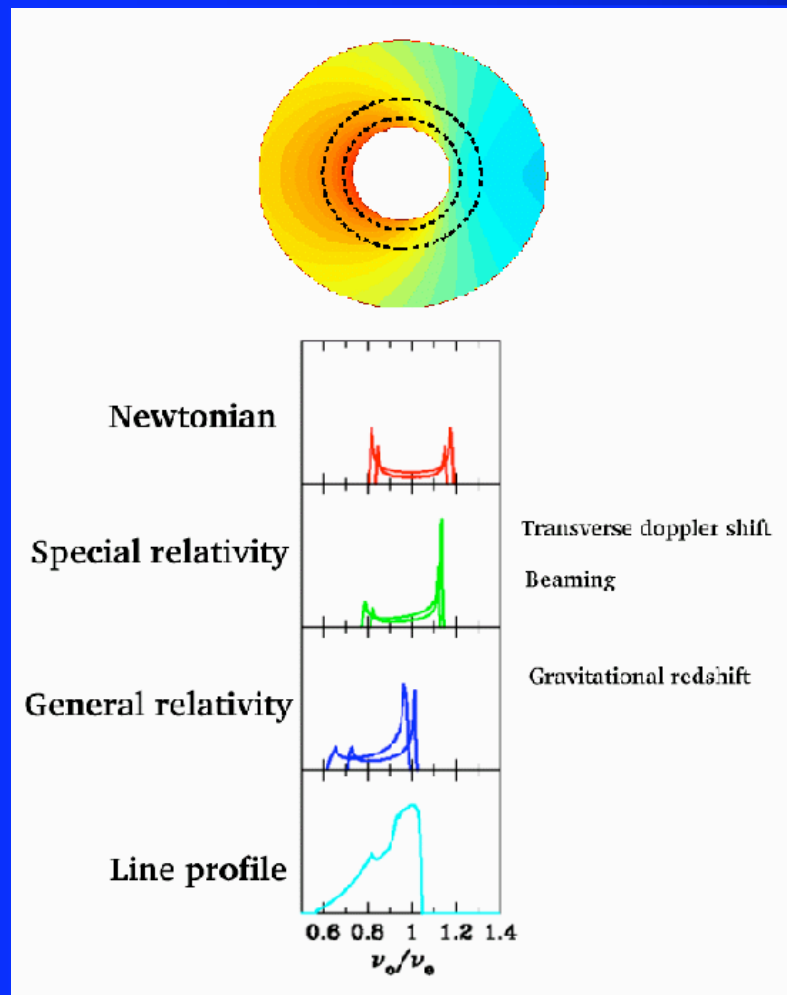
Basics...

- λ Supermassive black holes grow by **radiatively-efficient** accretion
 - Soltan argument; compare QSO background light with BH mass density
 - Luminous AGN must be efficient sources
- λ There is optically-thick, cold matter reaching very close to BH horizon in such sources
 - Continuity & Energy eqn.
- λ X-rays coming from very compact region (\sim horizon scales)
 - Variability



\therefore Ingredients for X-ray reflection from inner accretion disk are all present!

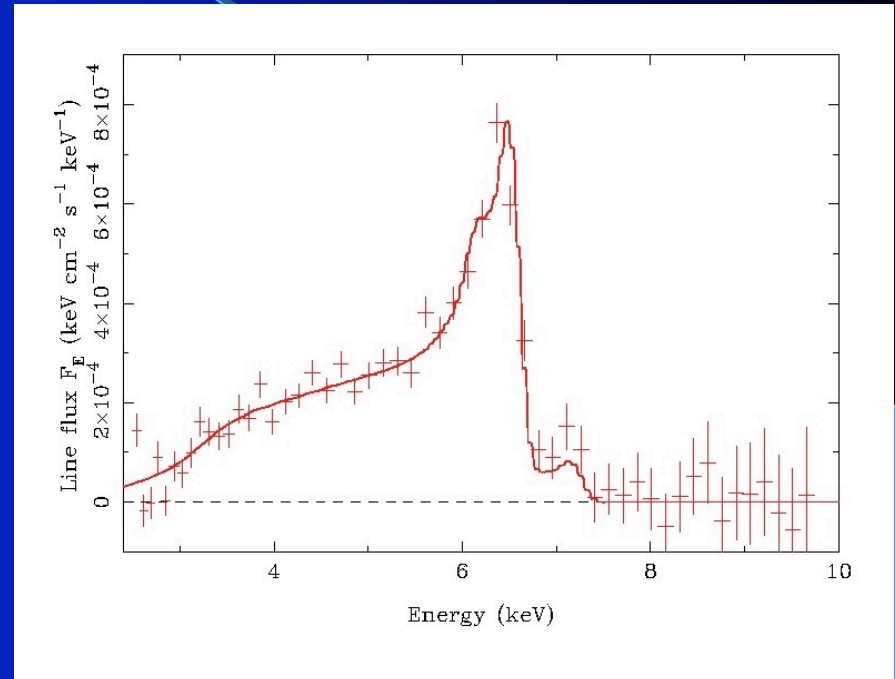
Relativistic (iron) emission lines



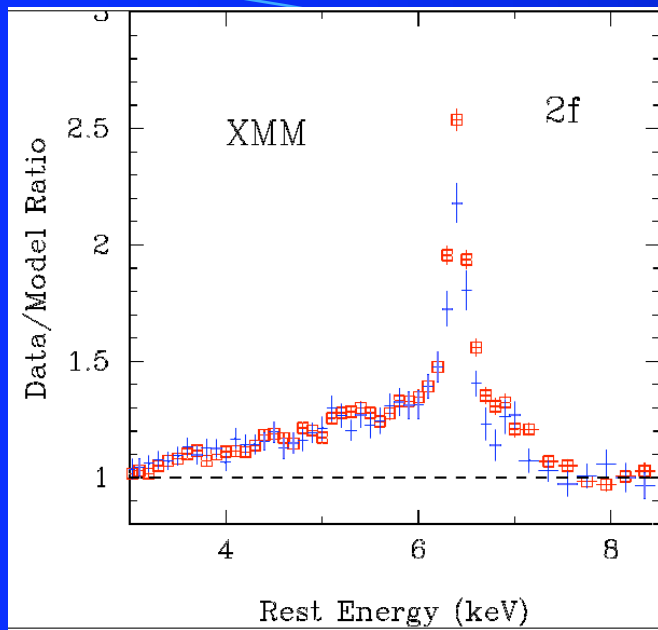
Iron line profile in
MCG-6-30-15
(Tanaka et al. 1995)

Strong gravity & accretion physics

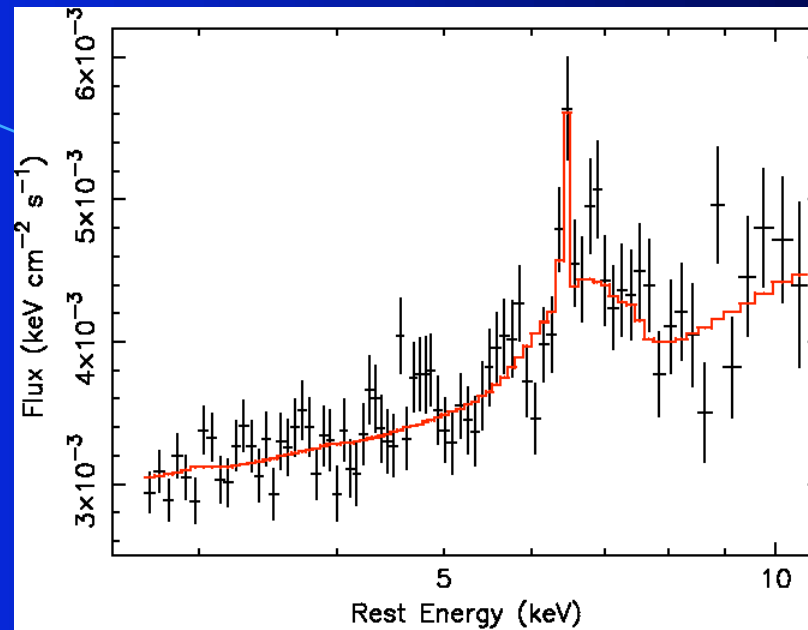
- λ Broad emission lines are the best understood probe of relativistic gravity
- λ Study of these features is alive and well in the XMM era



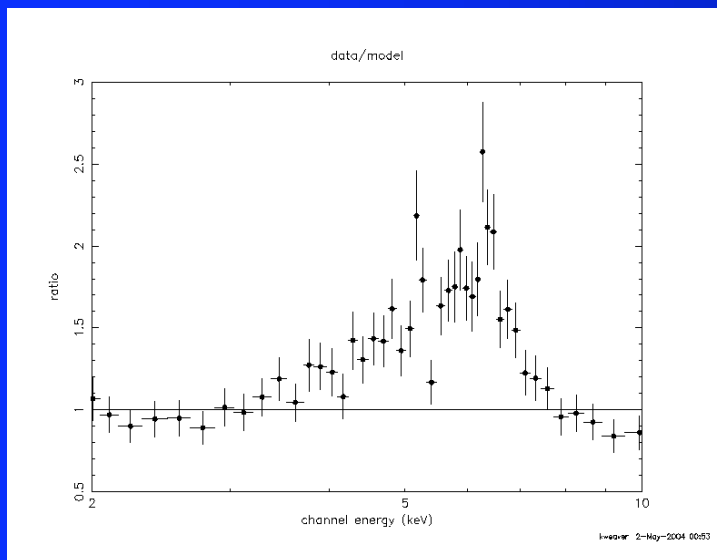
MCG-6-30-15
Fabian et al. (2002)



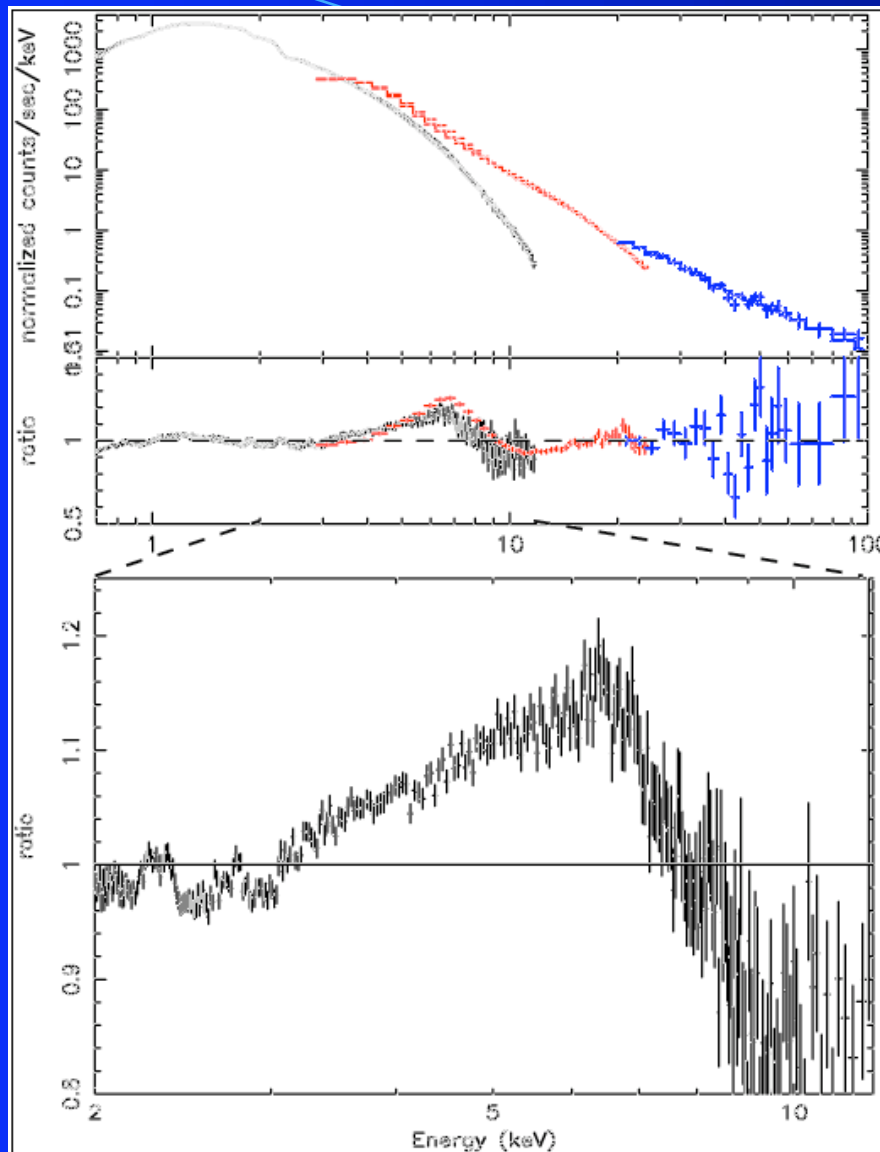
NGC3516
Turner et al. (2002)



Mrk205
Reeves et al.



LINER
(K.Weaver, in prep.)



J. Miller et al. (2004)

Galactic Black Hole Binaries...GX339-4

Iron lines in the XMM era...

- λ How robust is evidence that we're seeing strong relativistic effects?
 - Complex absorption (photoionized absorption etc.)?
 - Continuum curvature (including reflection continuum)?
 - Other broadening mechanisms?
- λ All these effects are calculable, producing detailed model predictions that can be compared with XMM spectra. But one needs to be careful!
 - Must stick to physical models (no random edges at arbitrary Es)
 - Must use variability info where possible
 - Distinguish “absence of evidence” from “evidence of absence”

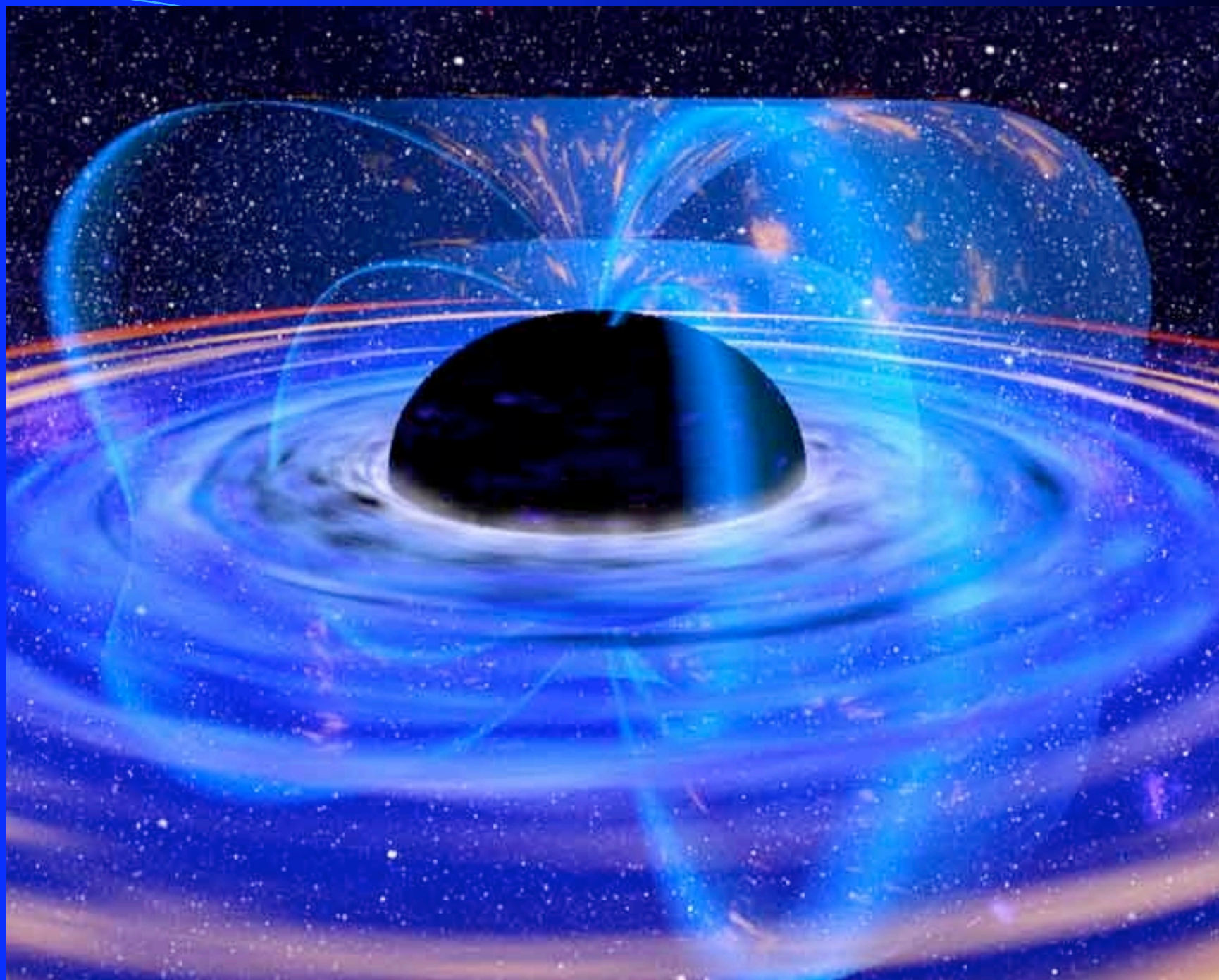
λ Bottom line from XMM

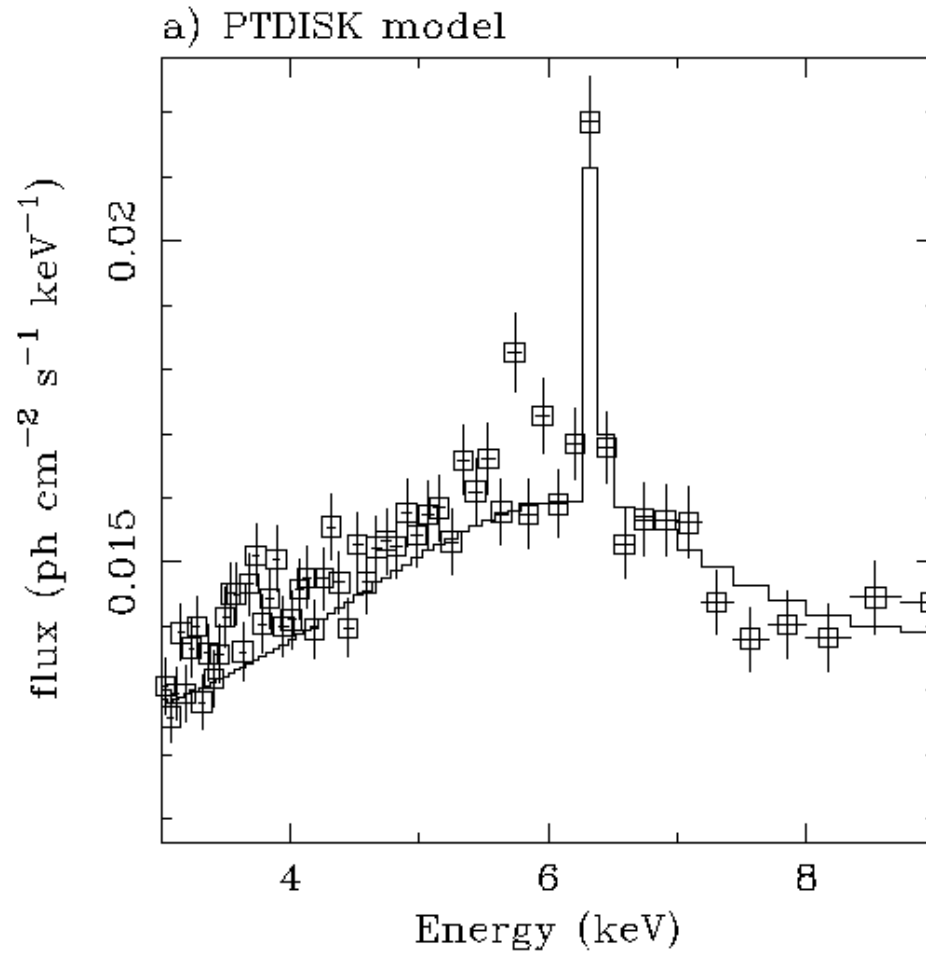
- There are a small number of very robust relativistic iron emission lines (MCG-6-30-15; GX339-4)
- At a lower level of robustness, ~25% of bright AGN have detected relativistically broad iron lines
- Many more may have undetected (weaker) broad lines
- The systematic, careful survey still has to be done.

λ **Even a few solid examples of relativistic iron lines in bright AGN allows Constellation-X to address its core scientific goals!**

A taster of the science currently being debated...

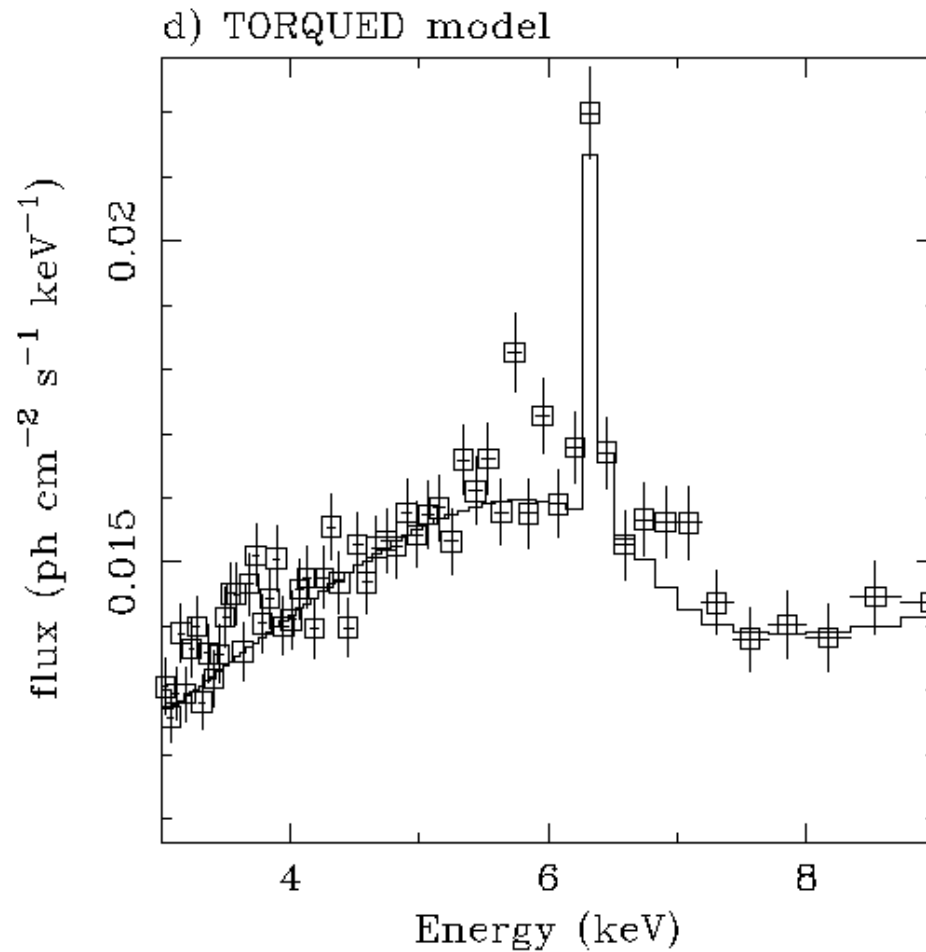
- λ We see **very** broad lines in MCG-6-30-15 and GX339-4
- λ Assuming validity of GR, the need for rapidly-rotating black holes is unambiguous
- λ **Very** centrally concentrated pattern of X-ray illumination needed to produce such lines
 - Strong light bending effects? (Fabian, Minutti, Vaughan et al.)
 - Magnetic torquing of inner accretion disk by spinning black hole? (Reynolds, Wilms et al.)
- λ Either way, we're debating processes occurring within the inner $2-3GM/c^2$



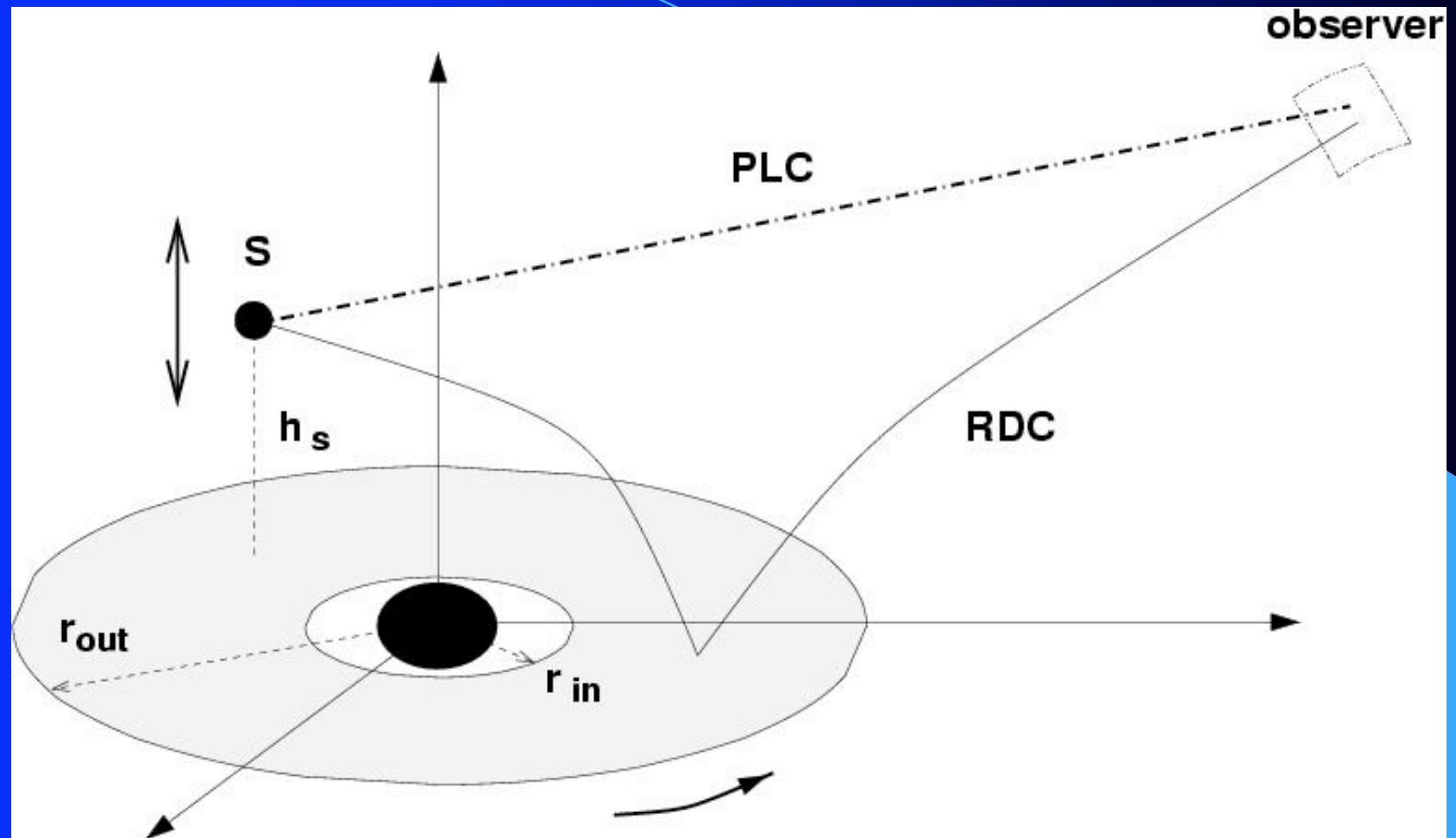


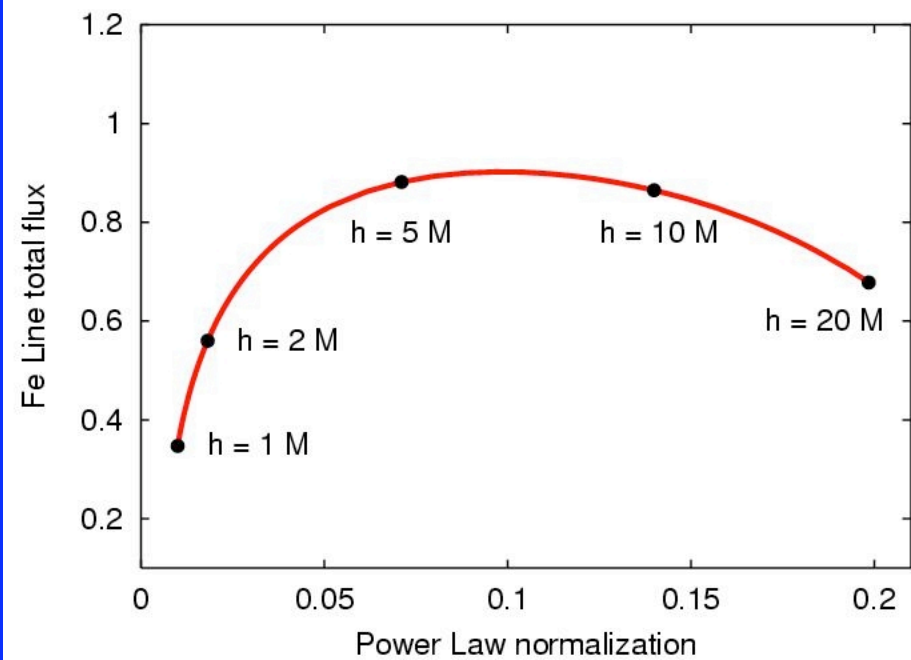
MCG-6-30-15

Fit with a Novikov & Thorne disk

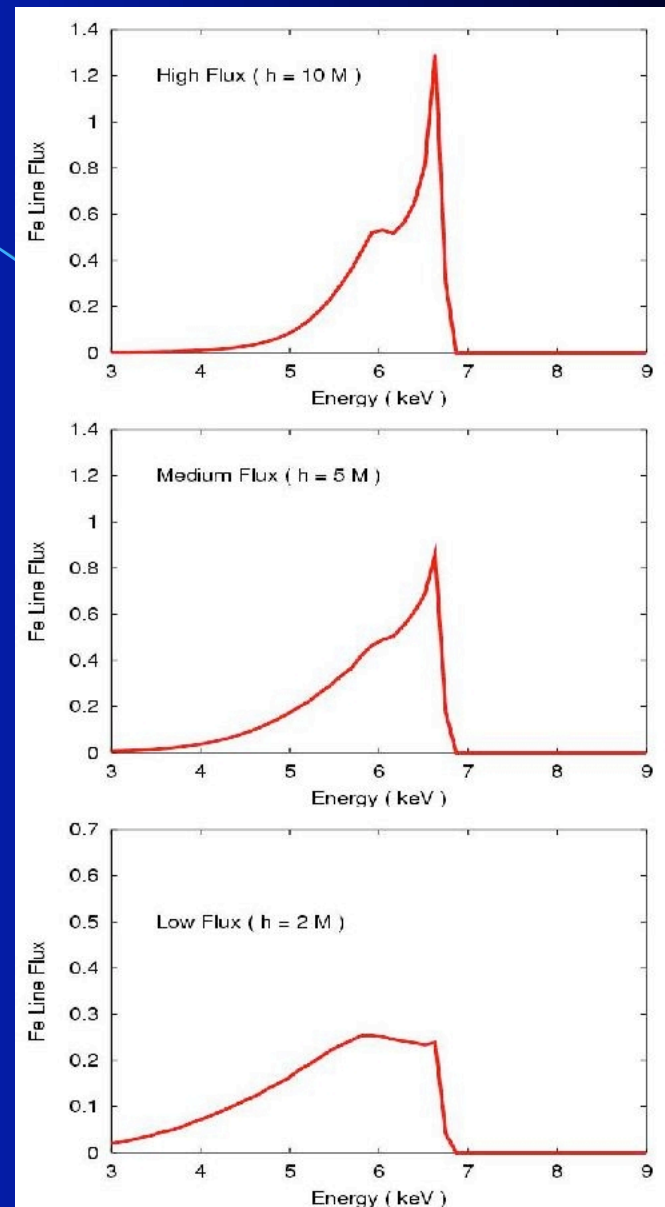


**Fit with a Agol & Krolik torqued disk
(need “infinite efficiency case”)**



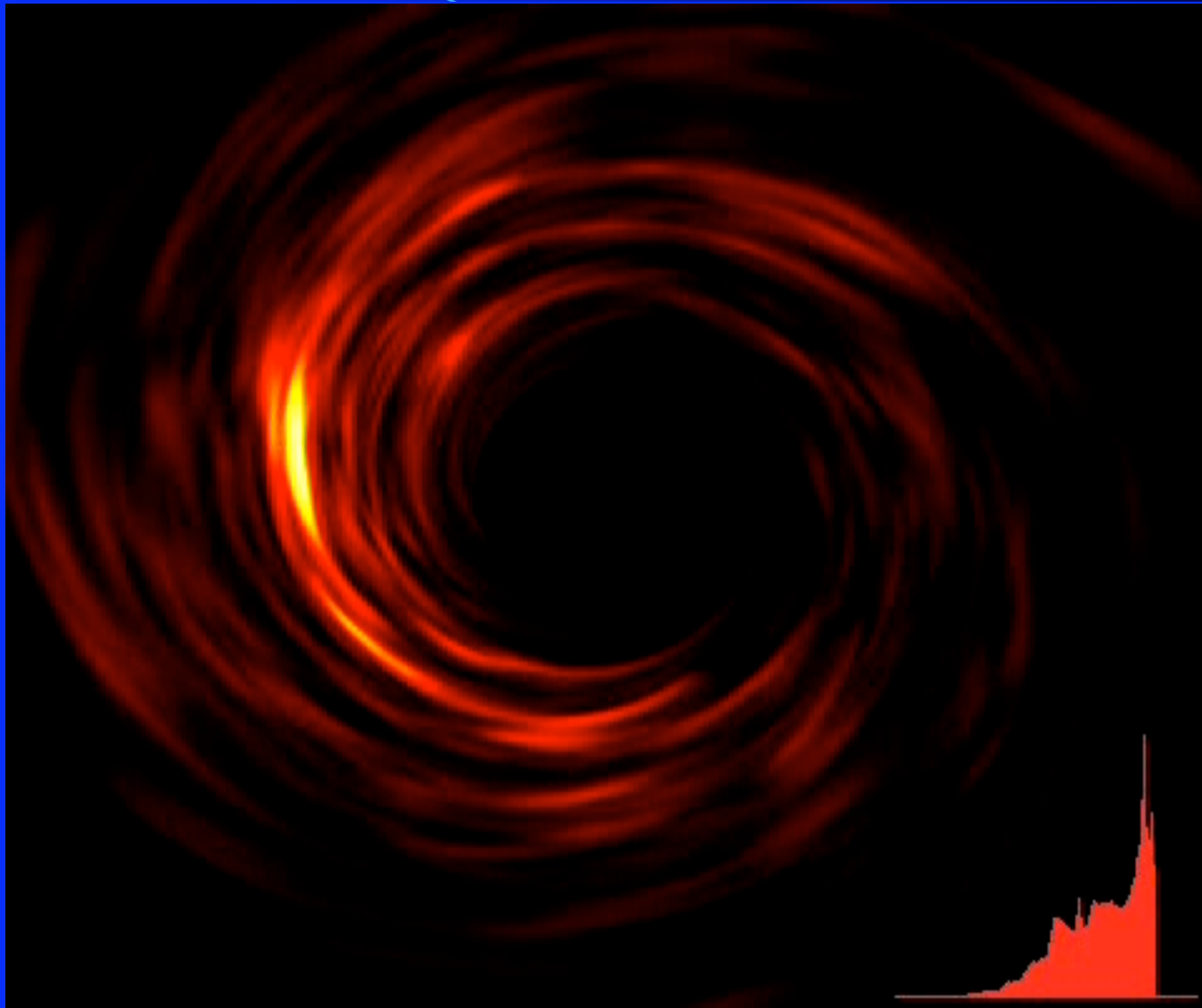


G.Minutti & A.C.Fabian



What can Con-X do?

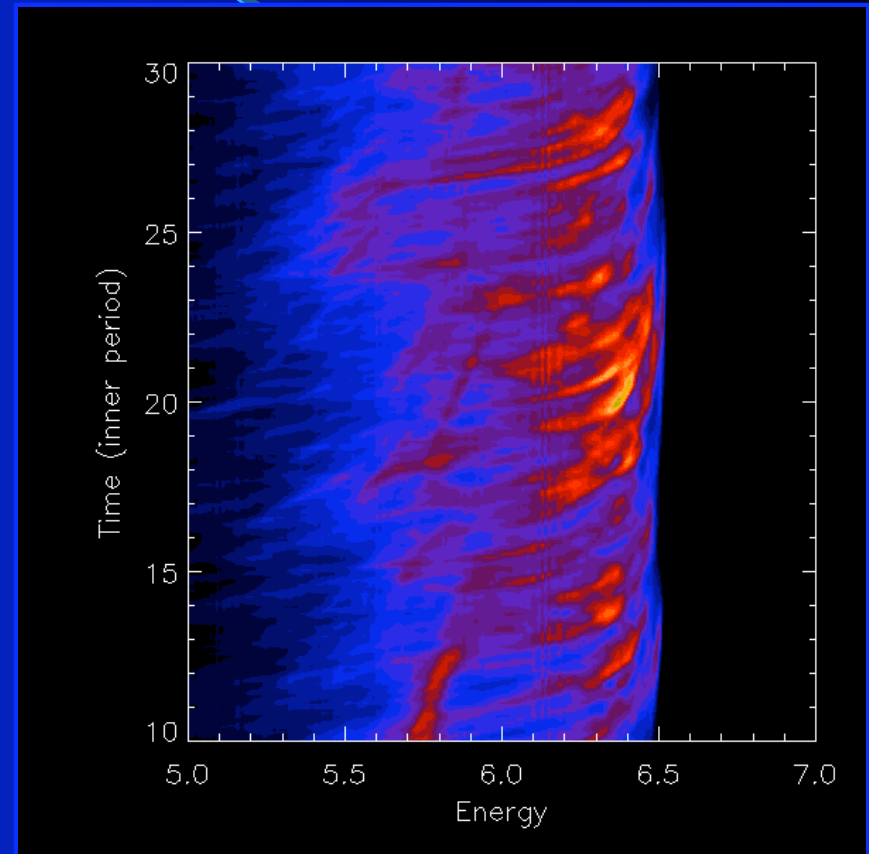
- λ Core science from detailed iron line variability
 - Structural changes in disk/corona (viscous timescale; XMM+)
 - Accretion disk dynamics (dynamical timescale; XMM++)
 - Reverberation effects (lightcrossing timescale; TRIP baseline+)
- λ Spectral properties of faint and distant AGN
 - Accretion history of BHs through cosmic time (how do BHs grow?); see Ann's talk.
 - Plasma physics of very low-luminosity AGN



Armitage & CSR (2003)

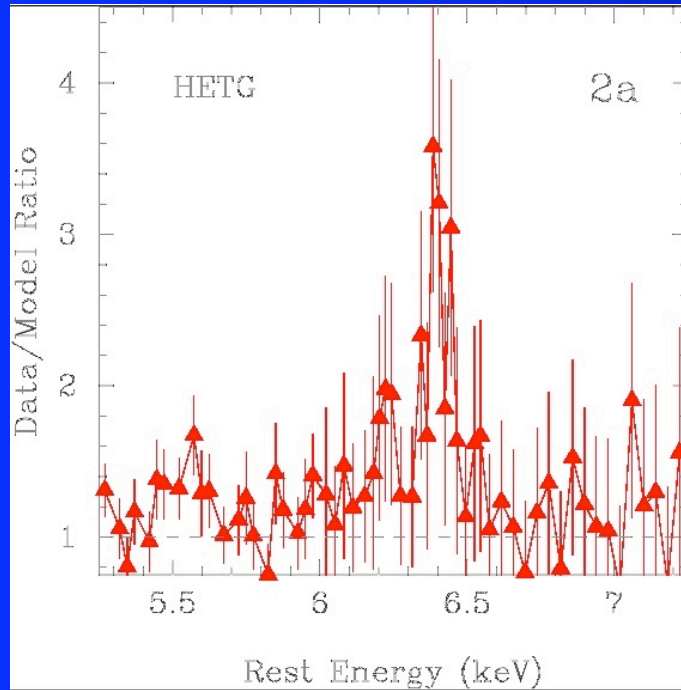
Iron line variability

- λ Con-X will allow detailed study of line variability
- λ See effects of non-axisymmetric structure orbiting in disk
 - Follow dynamics of individual “blobs” in disk
 - Quantitative test of orbital dynamics in strong gravity regime

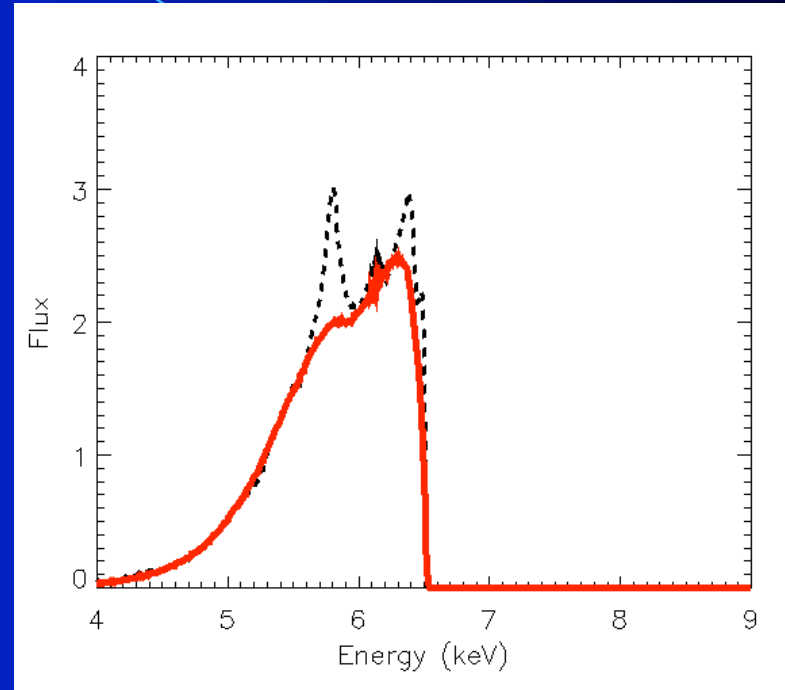


Armitage & CSR (2003)

Non-axisymmetric structure may have been seen already...



Chandra-HETG data on NGC3516
(Turner et al. 2002)



Simulation results for inclination
of 20 degs (summed over 2 full orbits)

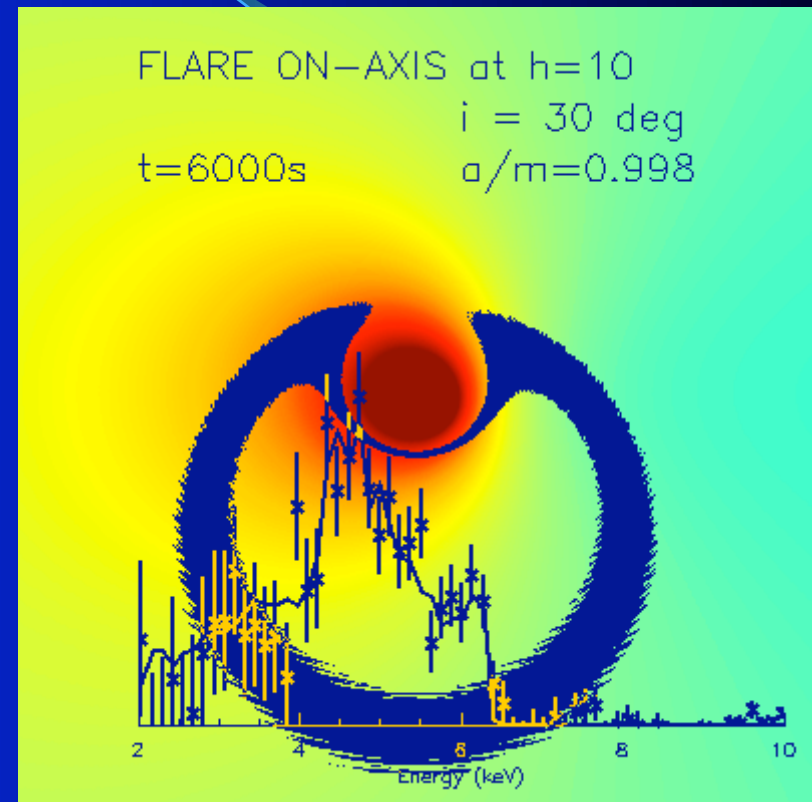
**Astro-E will further study of these features... but need
Con-X to realize full potential.**

Relativistic iron line reverberation...

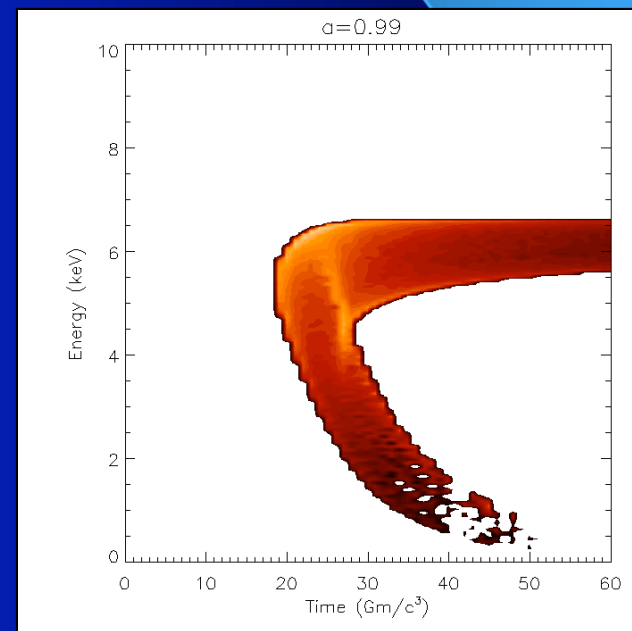
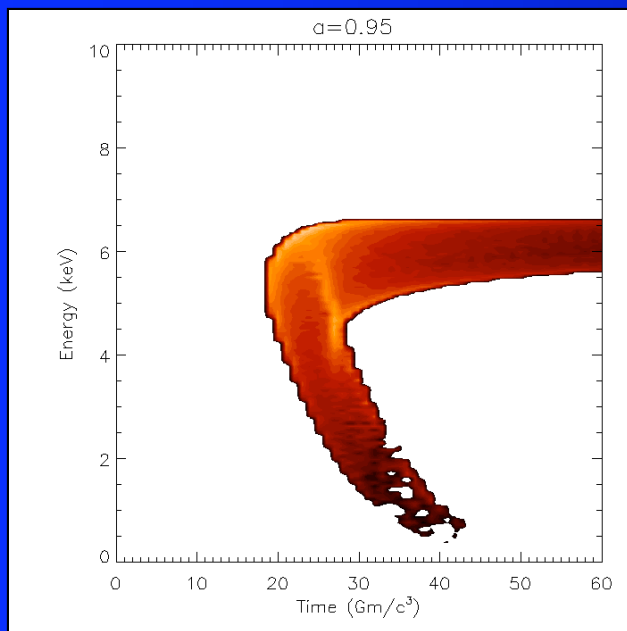
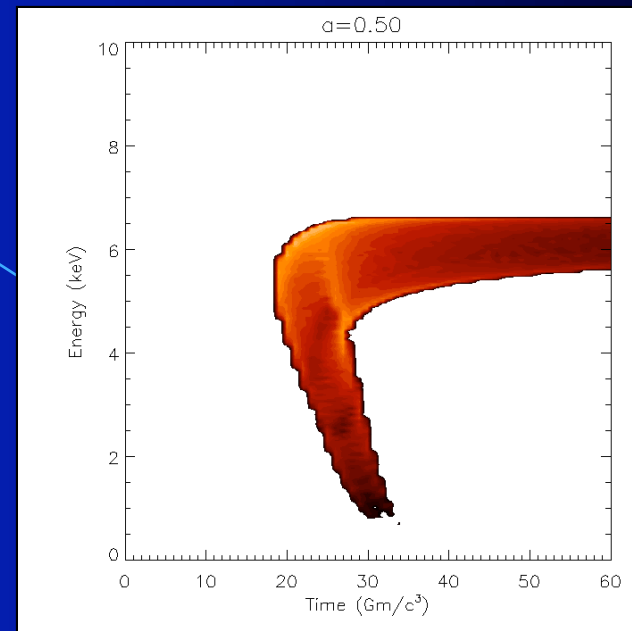
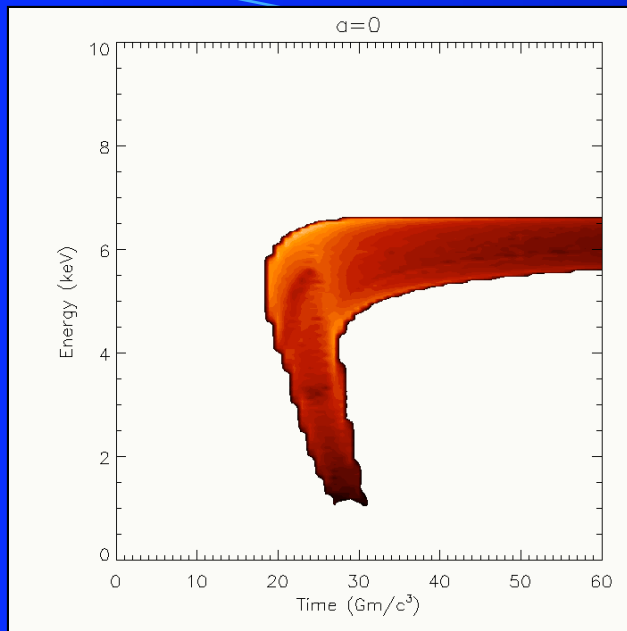
λ Reverberation

- X-ray source displays dramatic flares
- Iron line profile will change as echo sweeps across disk
- Needs high throughput spectroscopy – but probably within reach of 3m² Con-X

λ Current line variability results have **nothing** to say about feasibility of reverberation!



CSR et al. (1999)
Young & CSR (2000)



Reynolds et al. (1999)

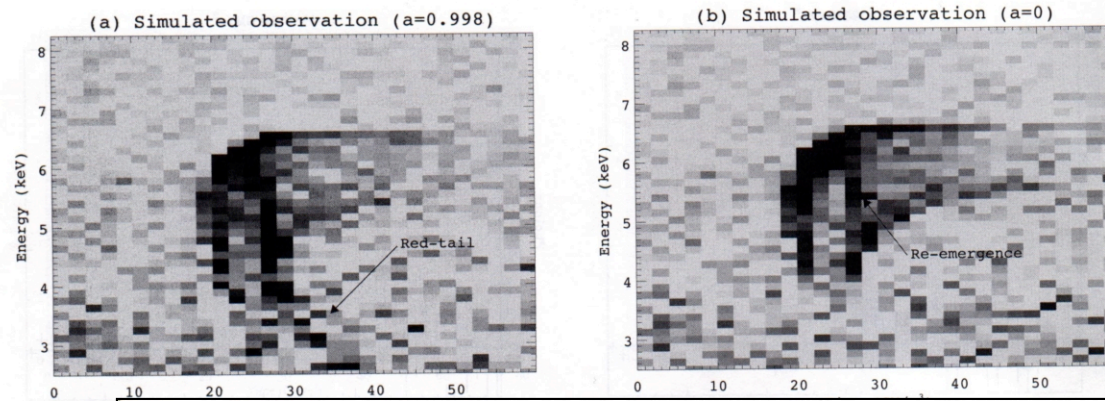


FIG. 4.—Sim
axis at a height
with improved

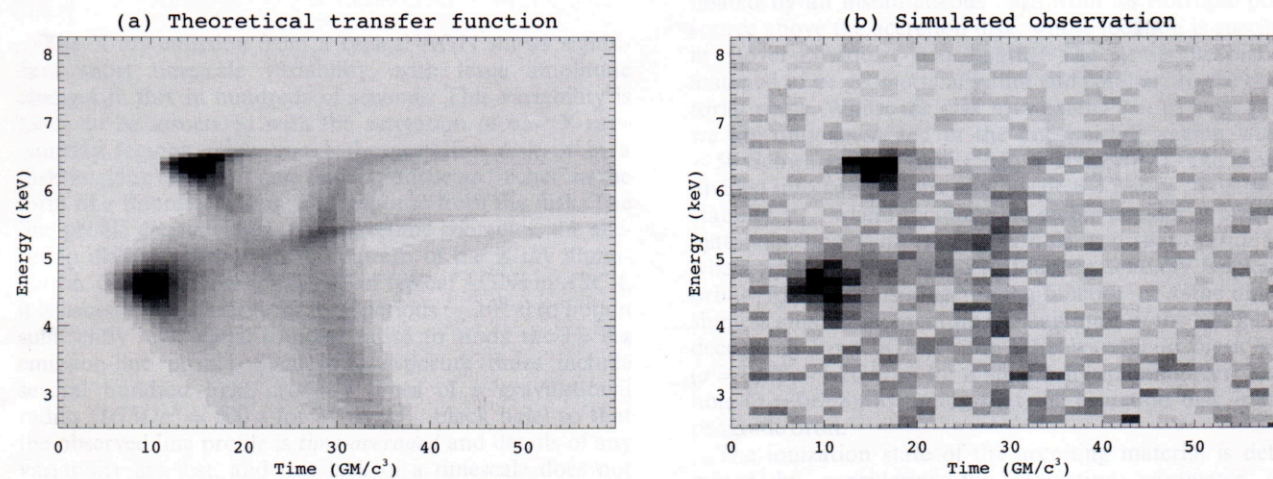
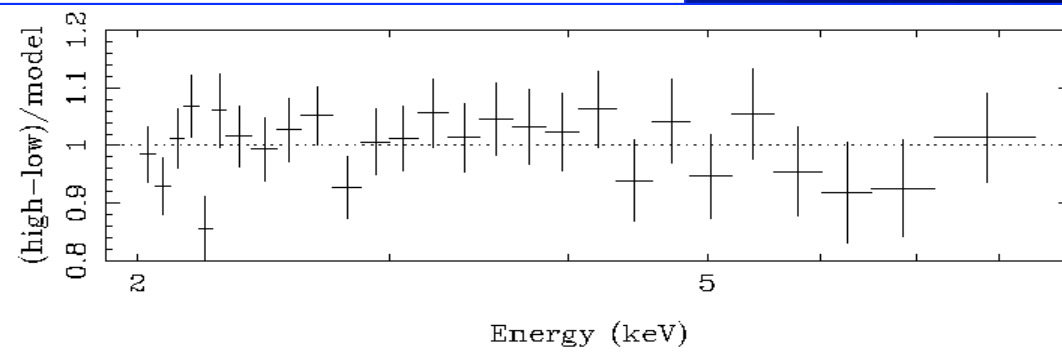
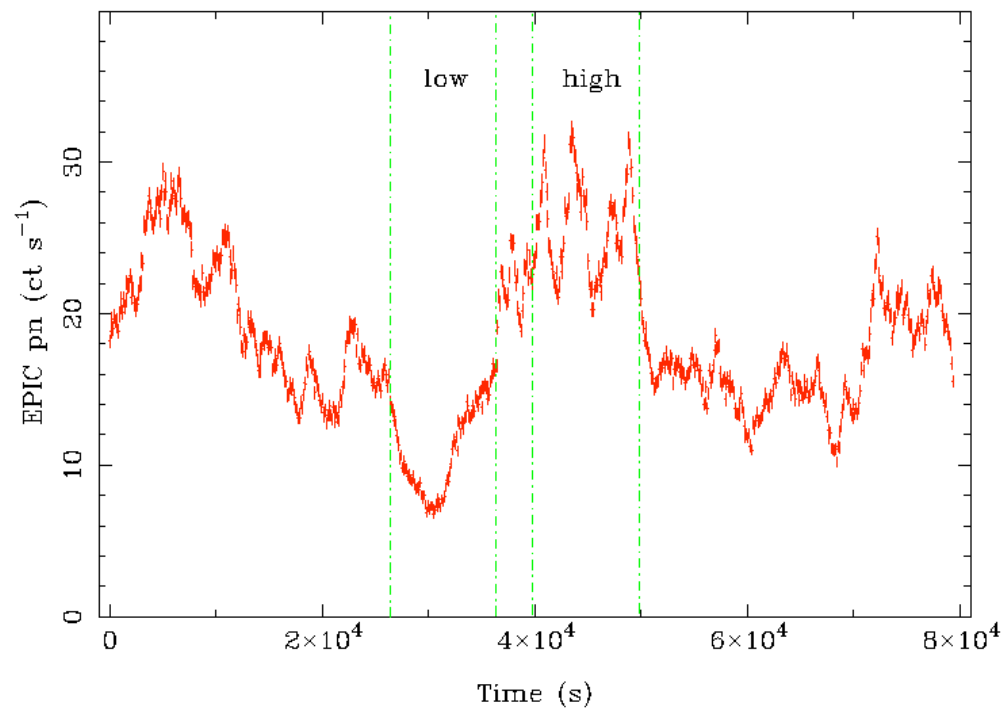


FIG. 7.—Panel *a* shows the theoretical line response to the two overlapping flares described in the text. Panel *b* shows the simulated line response as seen by *Constellation-X*. The individual transfer functions of the two flares can be discerned. The data have been rebinned to produce these figures with improved signal-to-noise ratio.

Constellation-X simulations

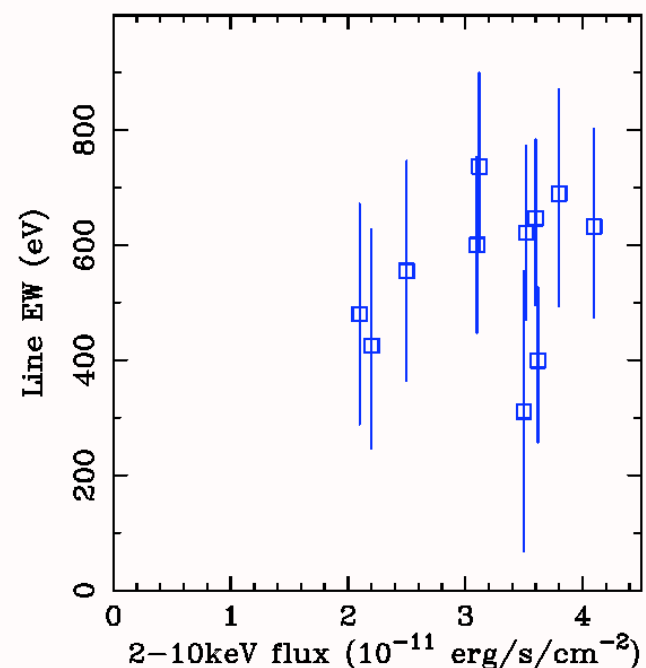
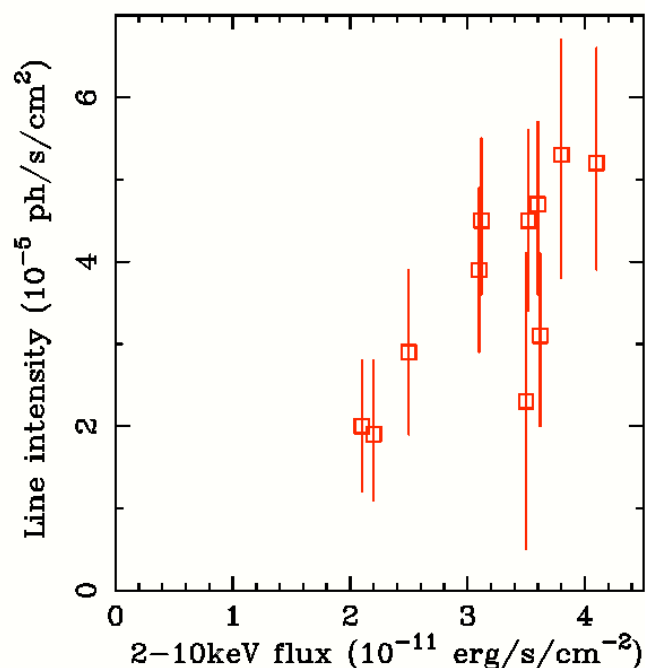
Conclusions

- λ **Black-hole core science** crucial to Con-X science case (at least while we're part of the Beyond Einstein Program)
- λ **Much of core science is accessed through variability of relativistically broad (iron) emission lines**
 - There are at least a few robust targets
 - We have well developed ideas of how to get at the big science questions
- λ **Need AREA and SPECTRAL RESOLUTION at iron K-band energies.**



Fabian et al. (2002)

Iron line tracks continuum flux in Deep Minimum State...



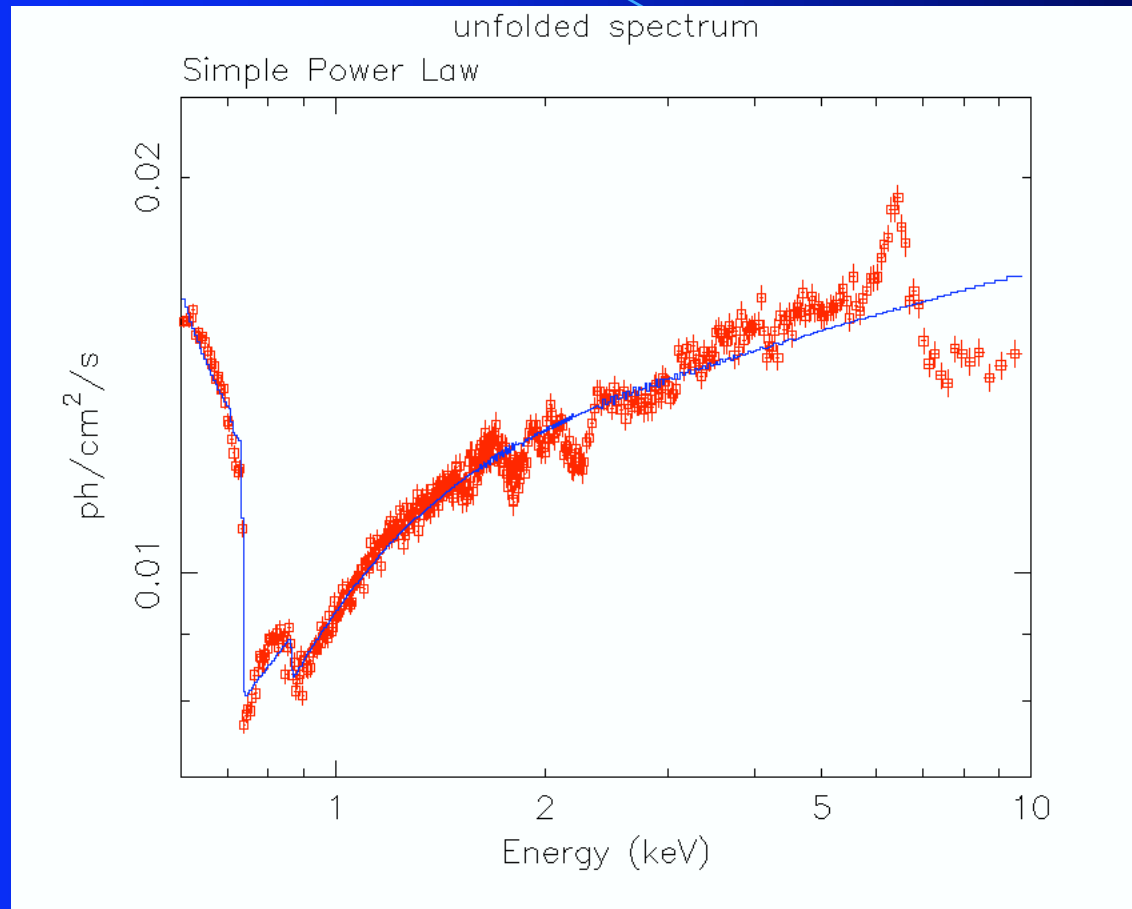
Overall behaviour is quantitatively explained by strong light bending together with changes in the size/height of part of the X-ray source... the “Two Component Model” (Fabian, Vaughan and collaborators)

Iron lines in the XMM era...

- λ How robust is evidence that we're seeing strong relativistic effects?
 - Complex absorption (photoionized absorption etc.)?
 - Continuum curvature (including reflection continuum)?
 - Other broadening mechanisms?

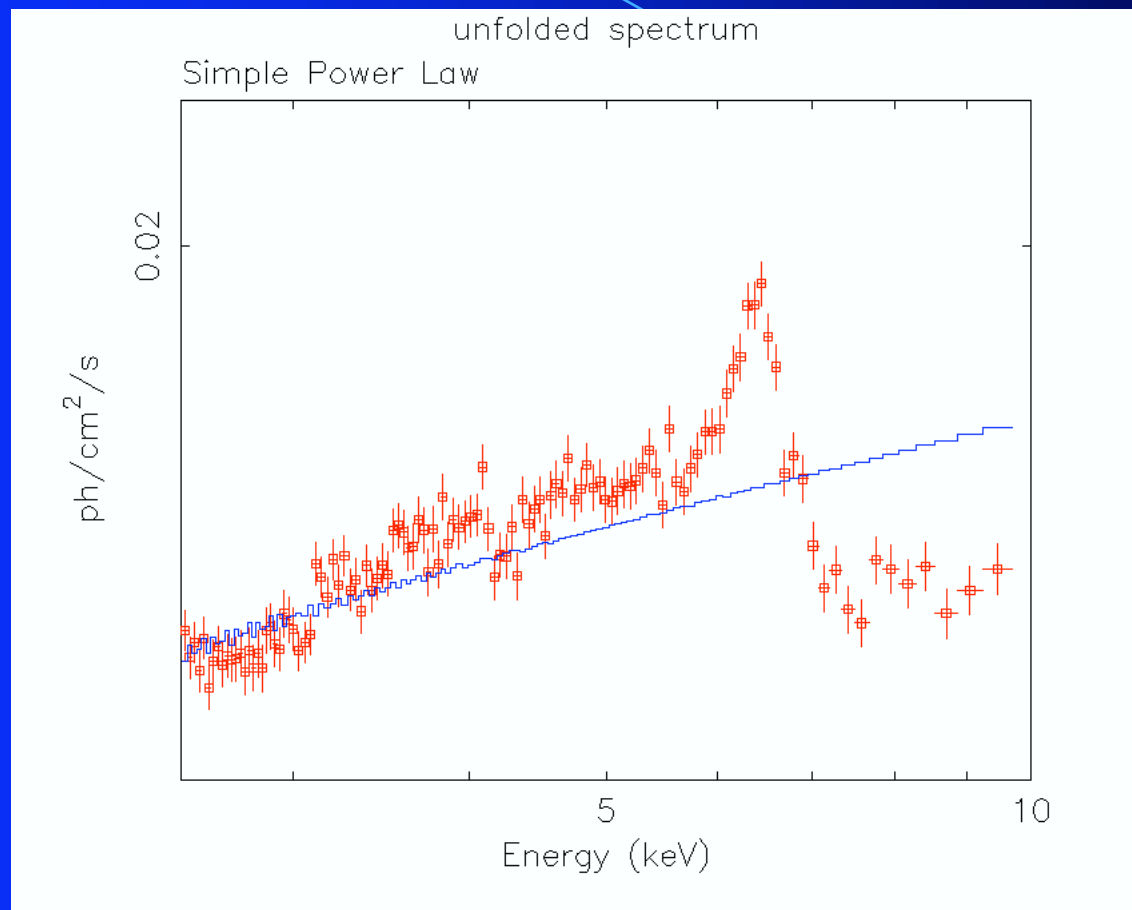
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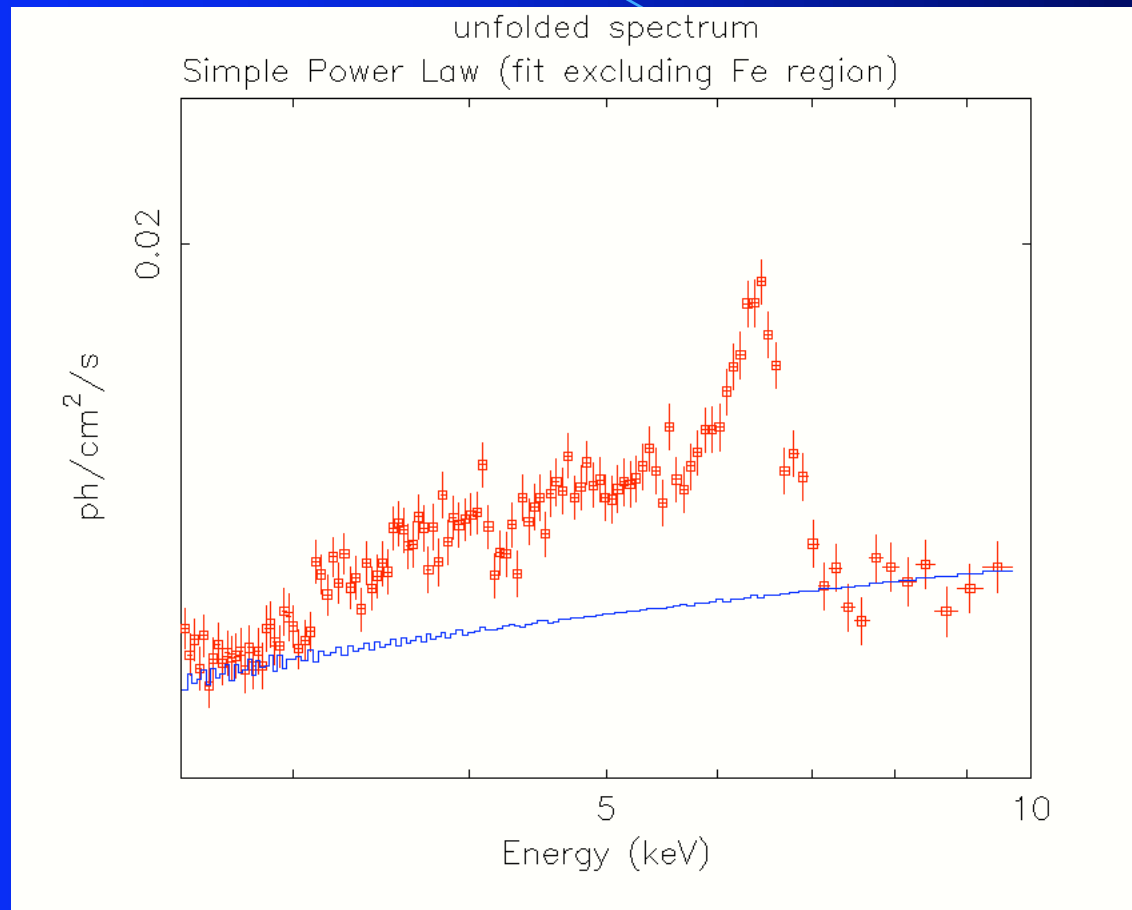
The poster child... MCG-6-30-15

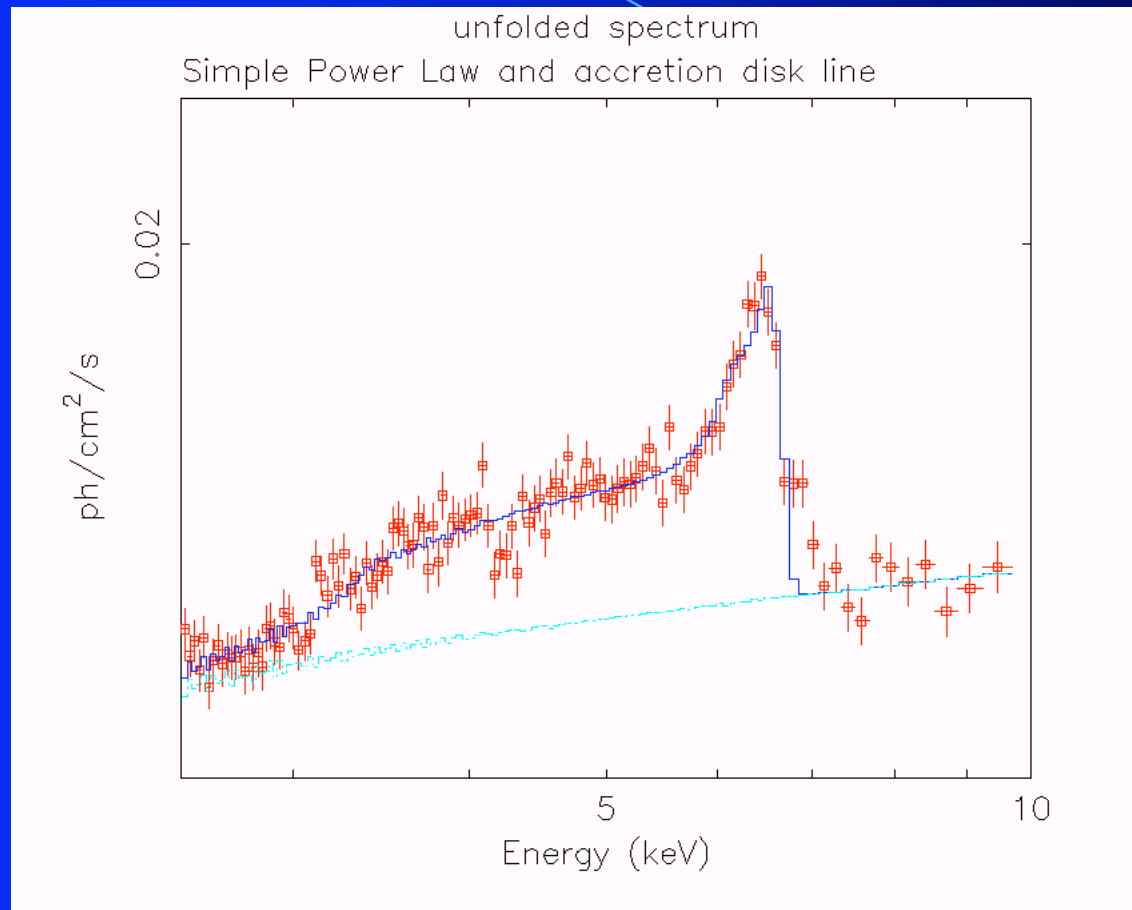


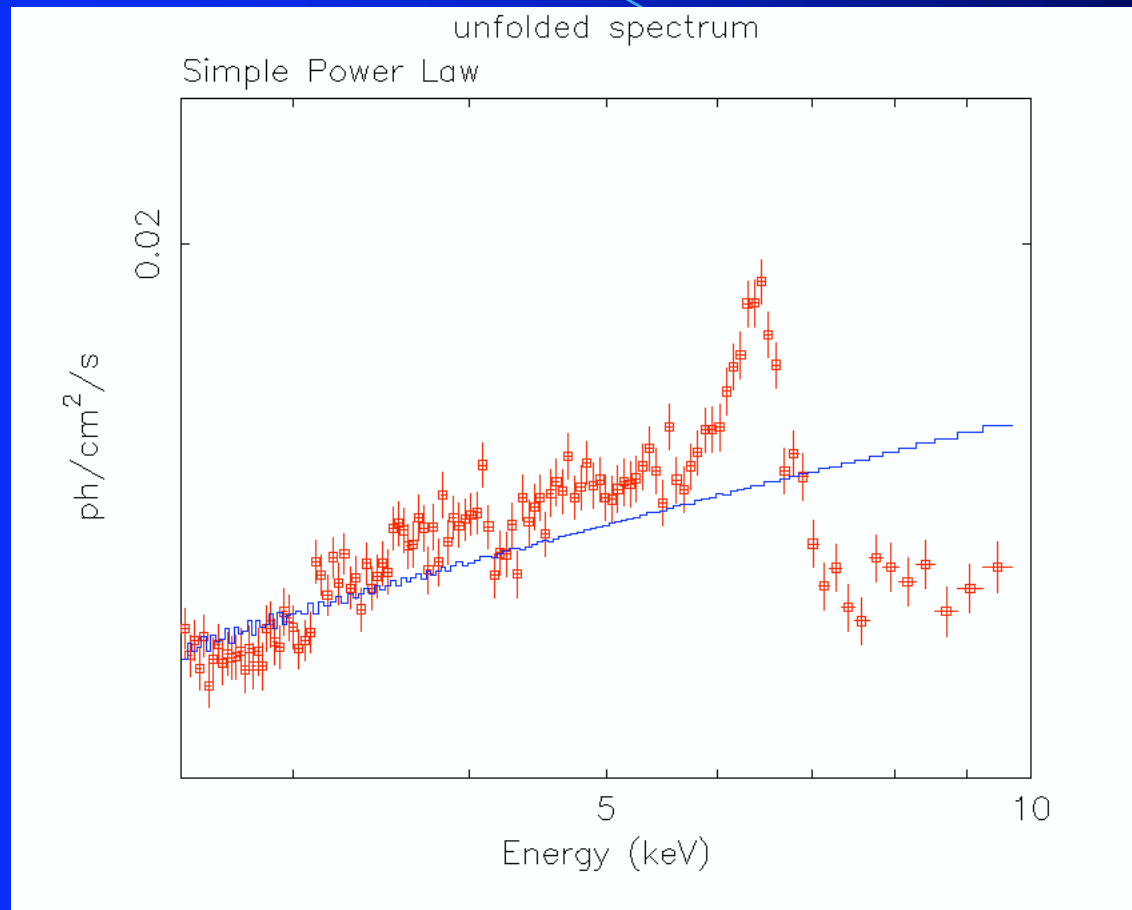
“Warm absorber” and “soft excess” included

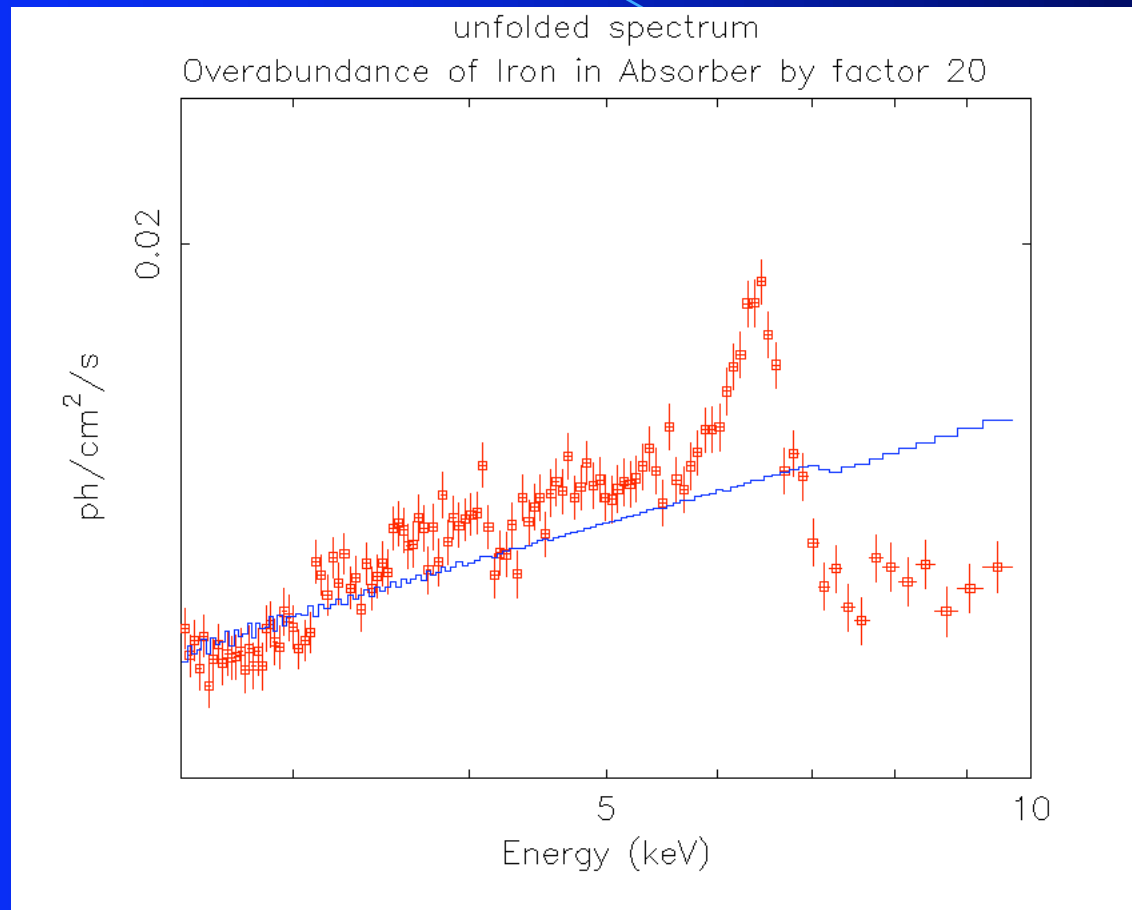
MCG-6-30-15

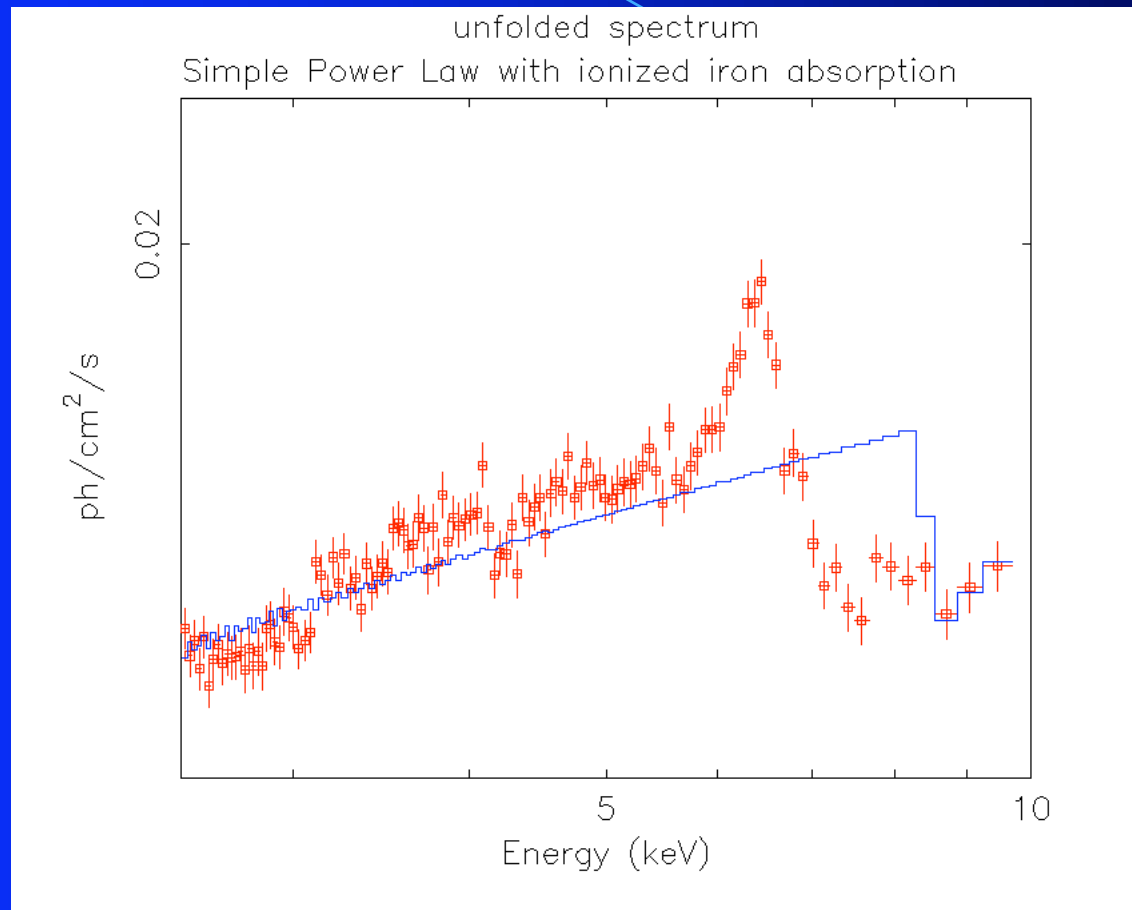


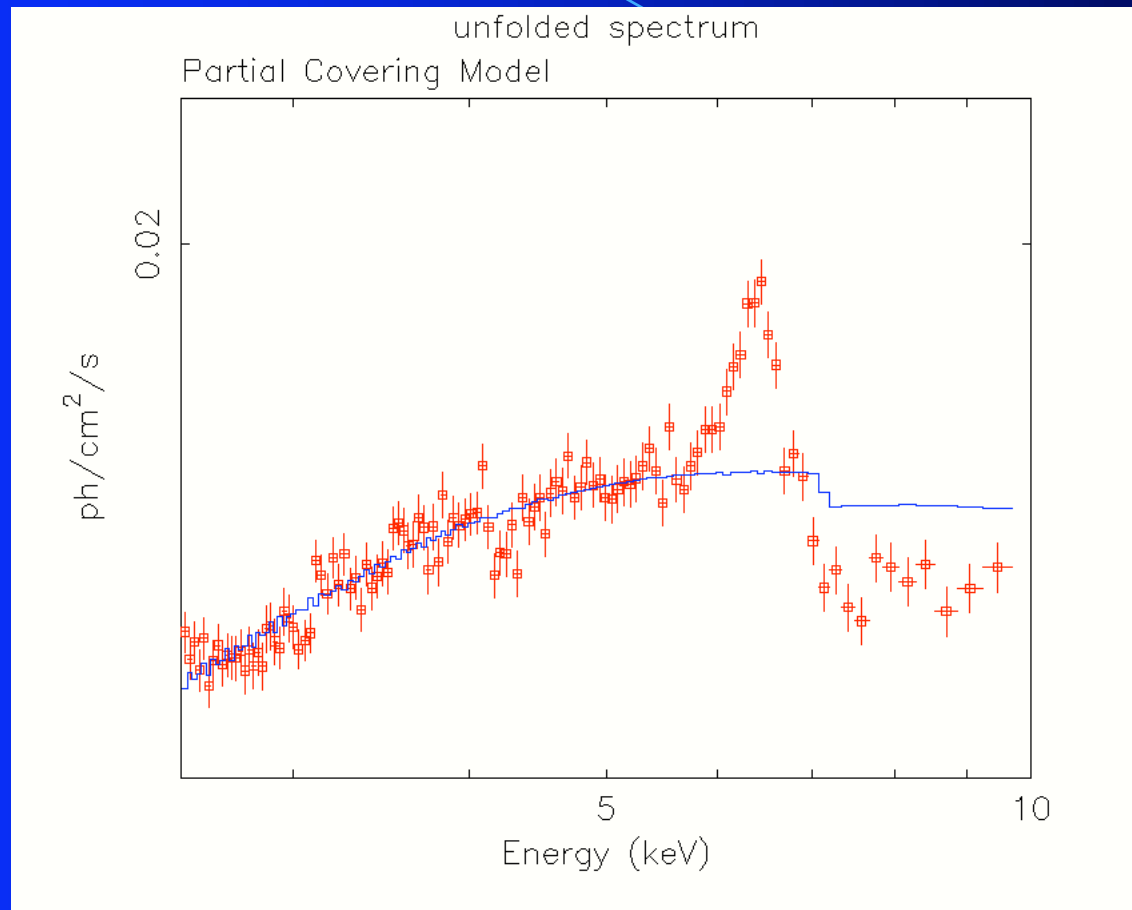


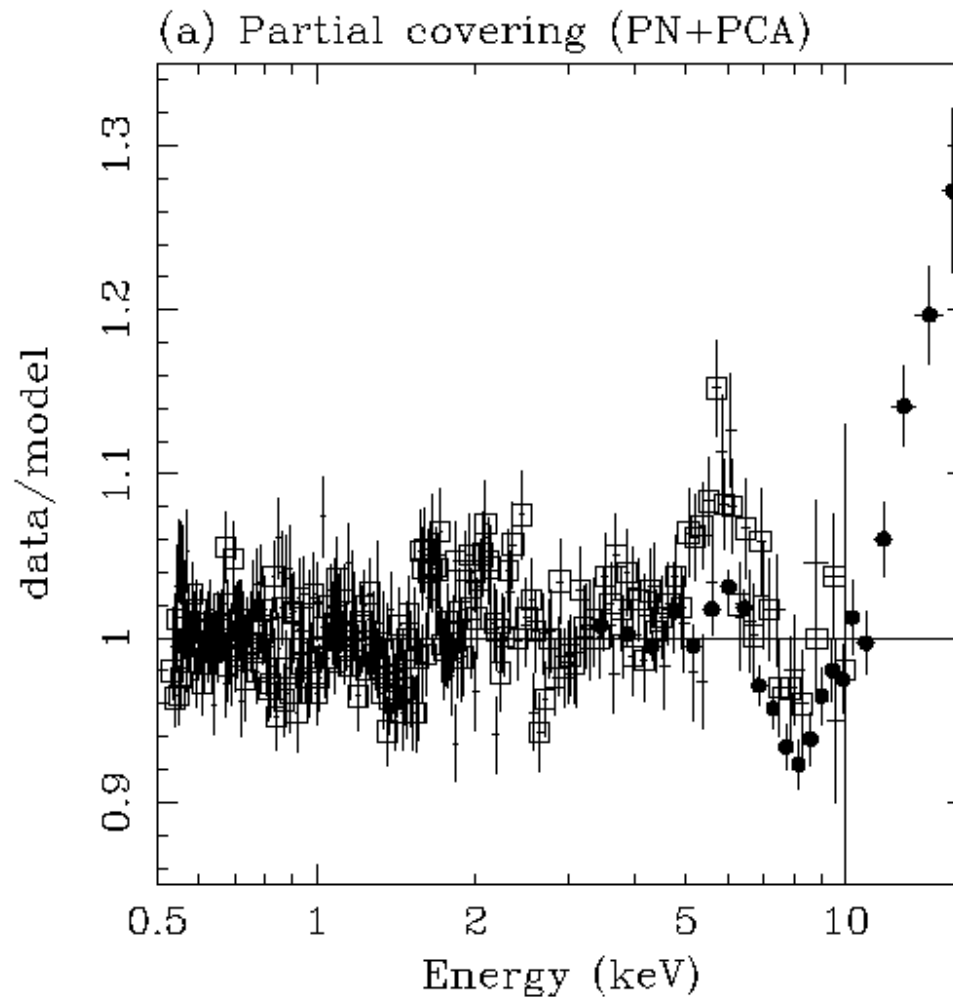












Partial covering requires steep continuum... disagrees with higher-energy data (e.g. RXTE)

Complex continuum shape?

